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HYBRID WIND/PHOTOVOLTAIC SYSTEMS FOR HOUSEHOLDS IN INNER MONGOLIA

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ABSTRACT

There are more wind turbines installed in Inner Mongolia, China than in any other region of the world. These 140,000 wind turbines provide electricity to about one-third of the non-grid-connected households in this region. However, these households often suffer from a lack of power during the low-wind summer months. This report details an analysis of hybrid wind/photovoltaic systems, using batteries but not using engine generators, for households in Inner Mongolia. These systems were designed using the optimization program HOMER and the simulation model Hybrid2. Various designs are compared on the basis of unmet load and annualized cost of energy. It is shown that combinations of wind turbines and photovoltaic arrays are more effective than either one alone over the estimated seasonal resource.

KEY WORDS

China, renewable energy, wind, solar, hybrid systems, rural electrification.

1. INTRODUCTION

There are more wind turbines installed in Inner Mongolia, China than in any other region of the world. These 140,000 wind turbines provide electricity to about one-third of the non-grid-connected households in this region. However, these households often suffer from a lack of power during the low-wind summer months. In an attempt to provide a more reliable source of rural electrification for these areas, this report details a preliminary analysis of hybrid wind/photovoltaic systems, using batteries but not using engine generators, for households in Inner Mongolia. The analysis procedure used is similar to that described in Lew *et al* (1996). These systems were designed using tools developed at NREL: the optimization program HOMER (Lilienthal *et al*., 1995) and the simulation model Hybrid2 (Green and Manwell, 1995).

2. RESOURCE

Monthly wind speed distributions at a 10 m hub height were provided for two Scenarios. Average wind speeds and the best fit to a 2-parameter Weibull distribution are shown in Table 1. Although

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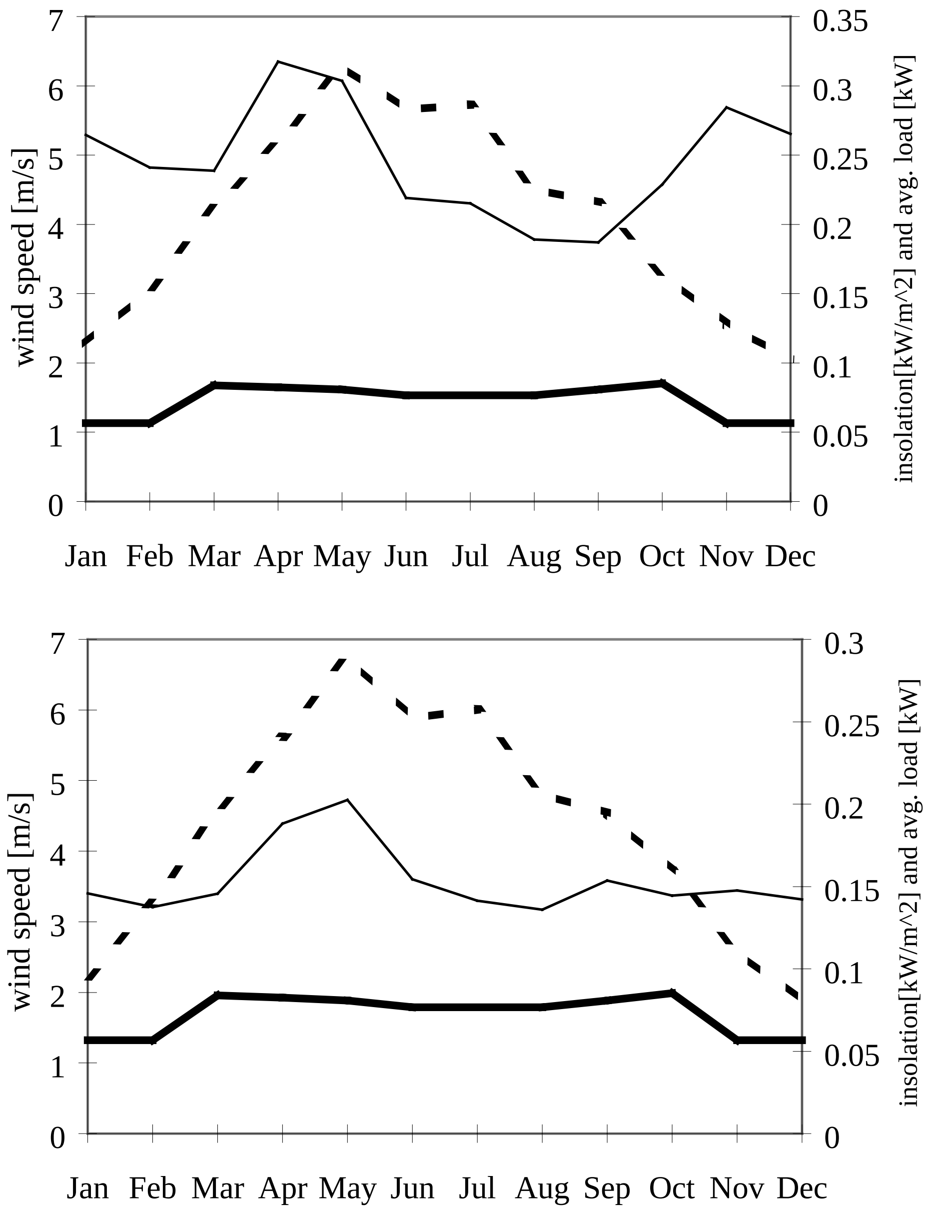

Figure 1. Wind and solar resource data for a) Scenario A and b) Scenario B in Inner Mongolia. Average wind speeds are represented by the solid, thin line; average insolation by the dashed line; and average load by the solid, thick line.

the Chinese have collected hourly data for the regions of interest, this data has not yet been obtained. This analysis will later be refined with hourly measured data for these regions. The data used in this analysis were three-hourly data obtained for Jurh for 1977-1979. Missing data was filled in using the assumption that the winds were constant over a 3 hour period.

The Jurh data from the late 1970's indicates a much better resource than is given for the two Scenarios. In remote areas, it is often seen that the average wind speeds decrease as a function of time (Schwartz and Elliott, 1995). This may be due to lack of maintenance on the anemometers or possibly increased construction of buildings near the anemometers. The given wind data is therefore somewhat suspect and may underestimate the wind resource. Consequently, the Jurh data was scaled so that average wind speeds were: 1) similar to those given above for each Scenario and 2) 1 m/s greater than those given above.

Scenario	elevation [m]	v_{avg} [m/s]	v_c [m/s]	k
Scenario A	990	4.9	5.2	1.7
Scenario B		3.6	3.7	1.4
Jurh, 1977	1280	6	~6.6	~2.2
Jurh, 1978		5.8		
Jurh, 1979		5.9		
Erenhot, 1962	966	4.4		
Erenhot, 1980		4.7		
Erenhot, 1984		4.3		

Table 1. Summary of wind data, measured at 10 m, for two Scenarios in Inner Mongolia. Wind data from the Jurh and Erenhot meteorological stations were used in these simulations.

Global horizontal insolation data was provided for each Scenario for a typical and a peak day for each month. Each day of the month was assumed to have the same insolation as the typical day. Figure 1 shows the resource data for the two Scenarios.

3. LOAD

A survey of current household loads in Inner Mongolia showed two general levels of electricity consumption: *high demand* households averaged 1075 kWh/yr and *low demand* households averaged 166 kWh/yr. In these analyses, a *medium demand* household of 633 kWh/yr was also modeled.

The high demand households generally have a continuous duty refrigerator load and may also have washing and drying machines, while both the low and medium demand households are assumed to not include a continuous load such as a refrigerator. In this analysis, a household load profile was derived from a community load in Inner Mongolia of 51 households which is currently served by a wind/diesel system. We scaled this profile to 166 and 633 kWh/yr loads for the small and medium household analyses. The high demand household loads were assumed to include refrigeration, which is a constant-duty 100W load. This refrigeration load plus the scaled household profile yield a total load of 1075 kWh/yr.

4. WIND TURBINES

The wind turbines modeled in this analysis included 4 Chinese turbines, 3 US turbines and 1 German turbine. The annual wind turbine output for the Scenario A wind resource is listed in Table 2. The lower turbine outputs due to the lower air densities found at these altitudes were taken into account in this calculation. The most cost-effective turbines, in terms of total installed cost per annual output, are the Chinese 200W and 2kW turbines. The Chinese turbines tend to have low hub heights (less than 10 m) and have been designed to accommodate the low wind speeds found at these heights. Figure 2 compares the power curves, normalized to the peak power for each turbine, of those turbines listed in Table 2. The Chinese power curves tend to rise more rapidly so that power can be generated at the low wind speeds which are found at the low hub heights of 6-10 m.

Turbine	peak power [W]	hub height [m]	rotor diameter [m]	annual output in Scenario A [kWh]	total installed cost [$]	total installed cost per annual output [$/kWh]
China						
Shangdu Livestock Machinery Works (SLMW) FD1.5-100	180	5	1.5	460	241	0.52
SLMW FD200	290	6	2.5	730	362	0.50
SLMW FD300	480	7	2.5	860	518	0.60
SLMW FD5.6-2000	2800	8.5	5.6	7000	2891	0.41
US						
Air 300	380	6	1.1	280	542	1.94
BWC 850	1050	26	2.4	1690	3930	2.33
BWC 1500	1700	24	3	2750	8184	2.98
German						
German Wenus 5kW	6200	12	6	8900		

Table 2. Comparison of small wind turbines from China, US, and Germany [Byrne, 1996b]. (Note that the Chinese tend to rate their turbines much more conservatively than is done internationally).

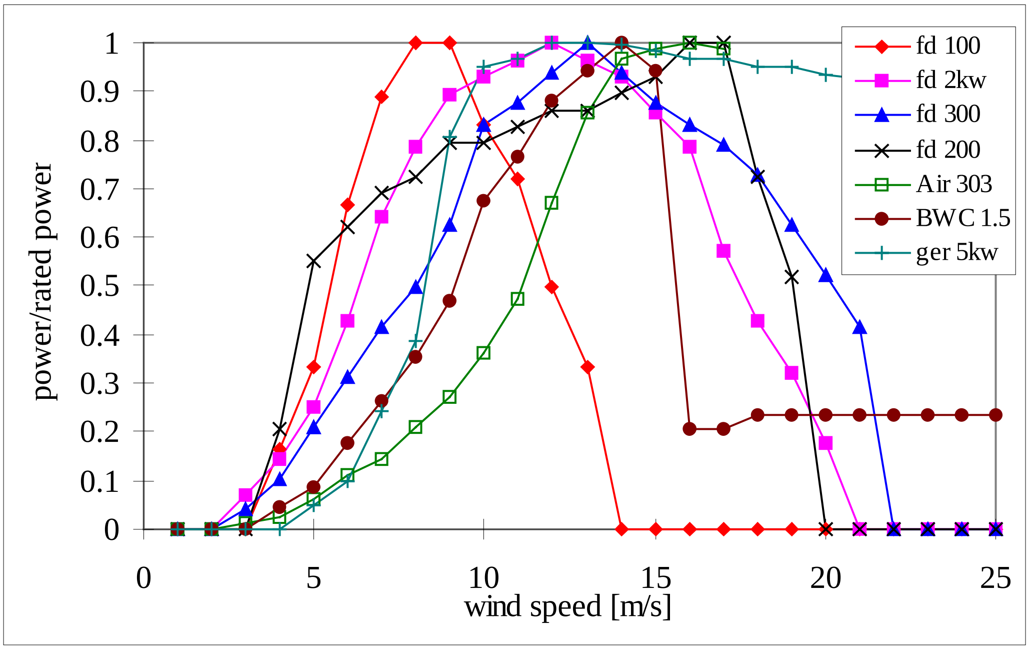

Figure 2. Comparison of scaled power curves from small wind turbines manufactured in China, US and Germany. (Note that the turbines from China are designed for the lower wind speeds that are present at low hub heights).

5. SYSTEM OPTIMIZATION

The optimization program HOMER was utilized to optimize the system configurations for a variety of household load sizes, from the average low demand to the average high demand. A 30% maximum depth of discharge was assumed in these HOMER runs, based upon specifications for Chinese manufactured batteries. The optimal system configuration output for Scenario A is shown in Fig. 3.

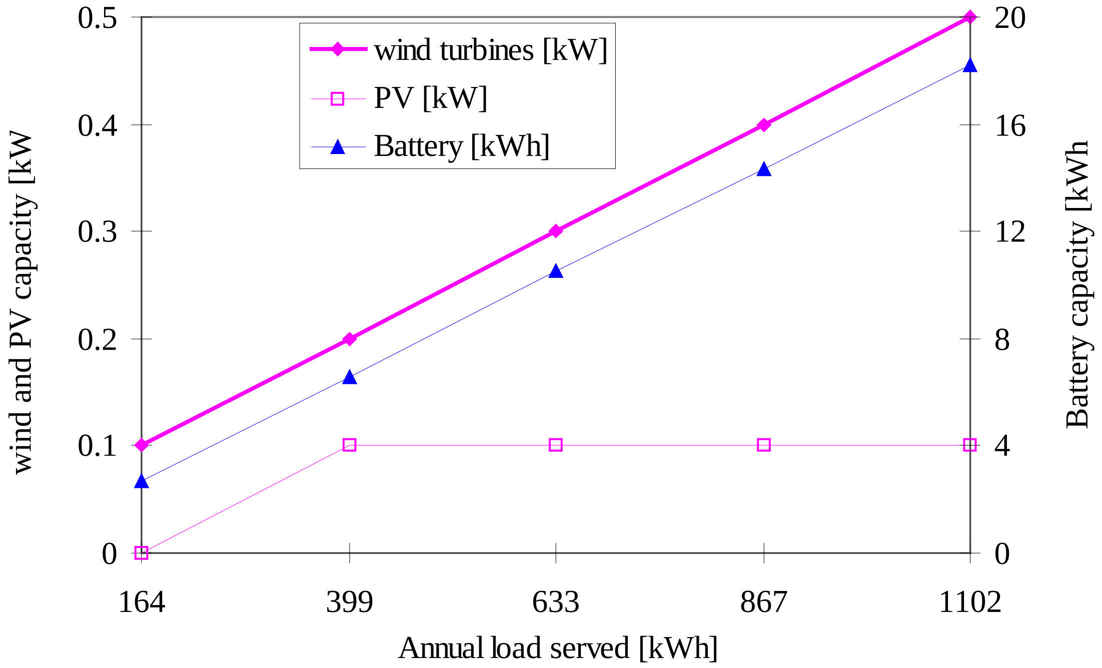

Figure 3. HOMER Analysis of hybrid systems for households for Scenario A. The analysis for Scenario B is similar.

The HOMER analysis indicates that a 300 W wind turbine and 100 W photovoltaic panel (PV) hybrid are ideal for a medium demand household with electricity consumption of about 633 kWh/yr. Both the low demand and high demand households will require different systems to minimize cost and adequately serve the demand. HOMER indicates that the PV capacity levels off with higher loads, which is an unlikely result. It is more likely that the resolution for the PV capacity is not high enough in these runs to show the slow increase of PV capacity with load size. This is borne out through further, more detailed analysis. HOMER results are simply used as a guide to narrow the options that will be considered in greater detail.

6. HYBRID2 ANALYSIS

Using the more detailed time-step simulation model Hybrid2, the system configuration was fine-tuned for the medium demand household with a load of 633 kWh/yr. Hybrid2 provides a more detailed level of analysis, including hour-to-hour weather patterns over the course of a year. Favorable solutions which result in 4% or less unmet load were similar to the HOMER solution. Battery component size restrictions and favorable economics for the Chinese 200 W wind turbine in particular, resulted in small differences from the HOMER solution. For Scenario A, the unmet load typically occurred in the summer months of August and early September.

Figure 4 depicts a summary of the indicated designs which feature a relatively low cost of energy (COE) in conjunction with a relatively low unmet load, for the Scenario A resource. The calculated COE values are higher than values calculated for existing systems in Inner Mongolia [Byrne *et al* 1996a], partly due to the use of higher priced system components, and partly due to the fact that excess energy in this analysis is not utilized and considered to have zero value. Additional sensitivity analyses will further delineate the impacts of component costs, resource variations, excess energy, and other factors.

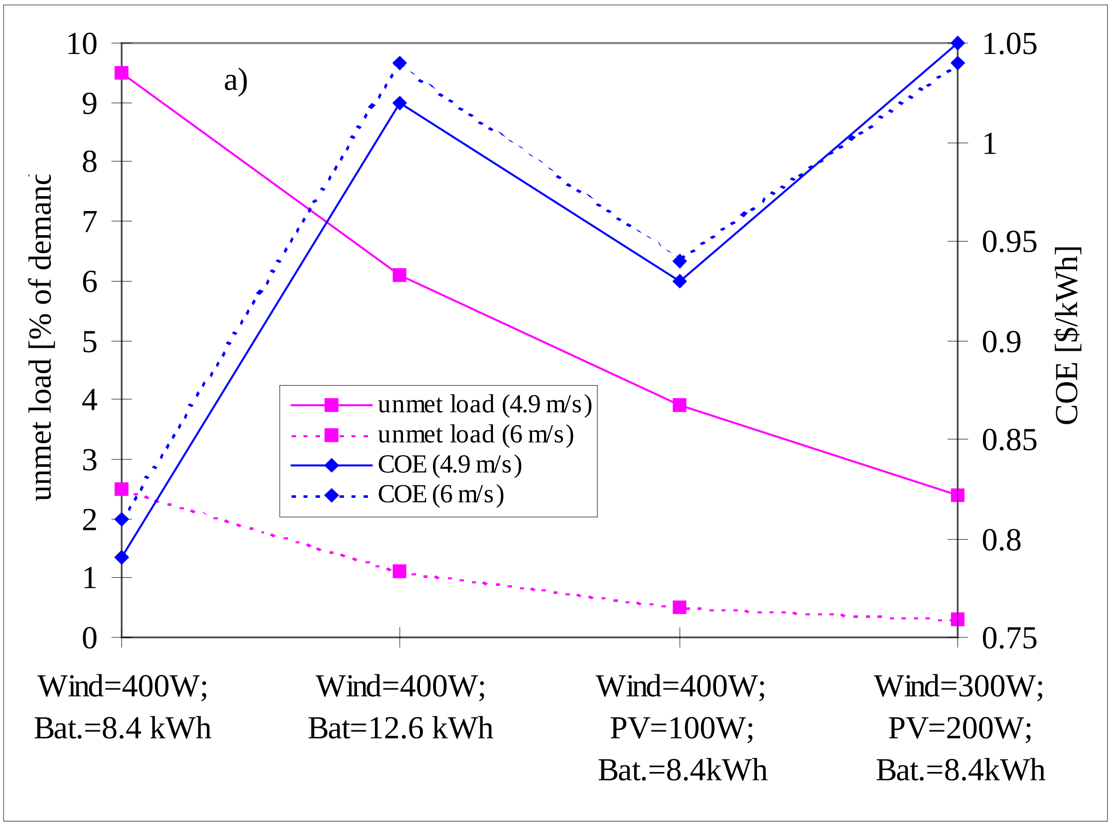

Figure 4. Hybrid2 analysis of medium demand household (633 kWh/yr) in Scenario A for an average wind speed of 4.9 and 6 m/s. Cost of energy and unmet load are shown for a variety of configurations.

The addition of PV helps to meet demand during the low wind summer months for a low incremental cost of energy. Due to the large uncertainties in the wind resource, both 4.9 and 6.0 m/s average wind speeds were considered in these runs. This illustrates the effect of estimating the resource incorrectly or of large variations in the interannual wind resource. The effect of this increase in wind speed on the wind-only systems is to reduce the unmet load by a factor of four. Reliability remains a problem in the summer months. Increased wind speed reduces the unmet load by a factor of 8 for the two wind/PV hybrids. Note that while the resource has a large effect on the amount of unmet load, it has little effect on the COE. For the case of 300W wind, 200W PV and 8.4 kWh batteries, a large amount of excess energy is generated. This energy can be used for optional loads such as a water pump or heating element; however, to simplify this analysis, it has been assumed that excess energy is not utilized. The COE does not include the excess energy. In 4.9m/s average winds, this configuration generates about 870 kWh wind power and 460 kWh solar power, 520 kWh of which is excess energy. Optimal system configurations, assuming that a 4% unmet load is acceptable, for Scenarios A and B are shown in Table 3.

PV is essential for household systems in Scenario B due to the poor wind resource. It is likely that wind resource variation will have a minor effect on these systems. For the case of 200W wind, 400W PV and 8.4 kWh batteries, about 400kWh of wind power and 850 kWh of solar power are generated. Approximately 400 kWh of excess energy is generated from this system.

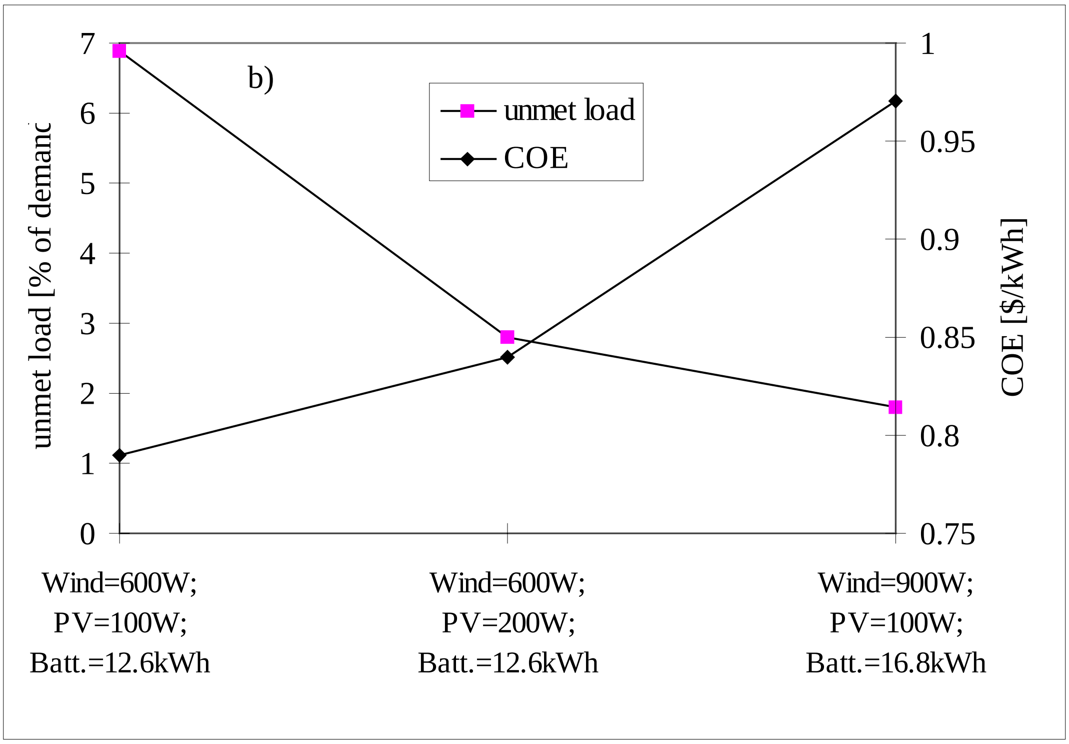

Figure 5. Hybrid analysis of high demand (1075 kWh/yr) households in Scenario A.

Various configurations were evaluated for the low and high demand households in Scenario A. The results for the high demand households are shown in Fig. 5. As to be expected, the COE decreases significantly as the load increases.

7. CONCLUSIONS

In the type of hybrid systems studied here, which do not include fueled engine generators to provide back-up power, alternative designs are compared based on unmet load as well as cost. The relative importance of these two criteria is a subjective judgement; thus we have presented our results so as to illustrate the trade-off and provide some options. Because the seasonal profiles of the wind and solar resources are complementary in this region (i.e., the wind speeds are low in the summer when the insolation is high), combinations of wind and solar perform better than either wind or solar alone. The greatest uncertainties in this analysis are the wind speed data and the battery data (price and cycle-life). As more precise data becomes available, this analysis will be further refined. Future work includes the design of wind/PV systems for villages in these regions.

8. ACKNOWLEDGEMENTS

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Item	capacity [kW]	country of manufacture	cost [$]
Scenario A			
wind turbine	0.4	China	724
solar module	0.1	US	682
battery	8.4 kWh	China	916
inverter	0.6	US	330
controller		US	110
Total			2762
Scenario B			
wind turbine	0.2	China	362
solar module	0.3	US	2046
battery	8.4 kWh	China	916
inverter	0.6	US	330
controller		US	110
Total			3764

Table 3. System configuration for Scenario A results in 4% unmet load at an average annual wind speed of 4.9 m/s. Costs include installation. System configuration for Scenario B also results in 4% unmet load. The annual per capita income for herdsmen in Scenario A is $152 (1260 Yuan) and in Scenario B is $392 (3255 Yuan). A 30% maximum depth of discharge and $109/kWh capital cost is assumed for these small sealed batteries from Yangzhou [Wang, 1996].

9. REFERENCES

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